MODIS Vicarious Calibration Workshop - Executive Summary

Wallops Island , Virginia 7-10 August 1995

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1. Introduction

The MODIS Calibration Support Team (MCST) invited a group of experts on vicarious calibration to attend a workshop at the NASA Wallops Flight Facility, Wallops Island Virginia on August 7-10, 1995.

The goal of the workshop was to identify vicarious data sets that could be incorporated into the MODIS calibration and data validation process that will produce the level 1B data product. This will be data that directly effects the coefficients used to transform counts into radiances, produce the estimates of the uncertainty of the radiances, and effect the modification history of those coefficients. Understanding the uncertainties of these data sets is of critical importance.

This executive summary of that workshop includes brief descriptions of some of the material covered in the workshop, some conclusions derived from the meeting, a list of the action items generated at the workshop, and a list of the people who attended the workshop.

2. Summaries of Presentations

2.1. Monday, August 7, 1995, Bruce Guenther, Welcome

The workshop convened with introductions and hopes for a productive use of our collective time.

2.2. Monday, August 7, 1995, John Barker, Workshop Overview

The workshop was expected to incorporate several components. There would be descriptions of the MODIS instrument and how on-board data would be used to establish a part of the calibration. Vicarious calibration techniques would be described. Uncertainty budgets for vicarious and on-board calibration techniques would be presented. Discussions of related topics like possible joint field campaigns and the logistics of incorporating vicarious data into the data system were scheduled. An unusual component of the workshop was that written worksheets were requested of the participants to evaluate each of the vicarious calibration techniques and their uncertainty estimates.

There were three worksheets for each technique. The first worksheet evaluated general opinions in a series of questions rated on a 1 to 5 scale. The second worksheet asked for detailed opinions about the sources of uncertainties in the measurements with prose answers. The third worksheet asked for a mock proposal to summarize the technique.

By the end of the week we found that the first two worksheets performed about as expected though some of the questions were ambiguous. The third worksheet for a mock proposal was not a success. A pair of questions about the major strengths and weaknesses of each technique added to worksheet two would have been more useful.

After each day the worksheets were collected and summarized over night. The original technique presenters responded each morning to the summaries. This combination of worksheets and responses worked to focus attention and eliminate areas of ambiguity. General agreement on both questions and answers was achieved for most topics.

2.3. Monday, August 7, 1995, Mike Jones, Reflective Band MODIS OBCs.

This was a background presentation about the MODIS On-Board Calibrators (OBC) and how they are used for radiometric, spectral, and spatial calibration in the solar reflective bands. The presentation described how the Spectroradiometric Calibration Assembly (SRCA) is used to monitor changes to the laboratory based spectral and spatial calibrations through the mission lifetime.

The ground based radiometric calibration of MODIS is based on a calibrated integrating sphere. The SRCA is used in its radiometric mode to monitor the radiometric calibration of MODIS from the ground into orbit. Once in orbit the radiometric calibration of MODIS is monitored and changed through the mission using measurements from the Solar Diffuser / Solar Diffuser Stability Monitor (SD/SDSM) system.

2.4. Monday, August 7, 1995, Peter Abel, HAUCSS

The objective of High Altitude Underflights to Calibrate Satellite Sensors (HAUCSS) is to calibrate Visible and Near Infrared (VNIR) satellite sensors with high absolute accuracy and short response and data turnaround time.

The objective is achieved by recording several spectra of a suitable target with a well calibrated spectrometer on an aircraft. The ER-2 aircraft flies at 19 km to minimize the atmospheric path correction. The aircraft underflies the satellite so that the satellite and the spectrometer observe the target with congruent geometry. The measured spectra are corrected to satellite altitude with LOWTRAN-7 and convolved with the satellite spectral response functions. The navigation is fine tuned with spatial correlations with the satellite counts. Comparisons between satellite counts integrated over the spectrometer footprint and radiance at the satellite altitude determine the gains.

The presentation continued with details of the instrument, the calibration, the experiences with this technique for GOES and AVHRR, and details of the uncertainty analysis. The uncertainties presented were 3.2% in the 550 nm to 1000 nm region. Improvements in the instrument would be expected to lower that to 1.8% uncertainty, improve the registration to MODIS pixels, and extend the observations over the wider MODIS VNIR spectral region.

2.4.1. Feedback

Members of the workshop considered this to be a valuable well understood technique. In the spectral range that it addresses it is as accurate as any available method. There was a belief that it should be supported at the level required to be used by MODIS.

2.5. Monday, August 7, 1995, Peter Abel, THOR

This was an brief informational talk on a project to Take Humidity Out of Radiance (THOR). This is an on-going project to instrument an integrating sphere with a spectrometer to determine the water within the sphere and how it effects the radiant output.

2.6. Tuesday, August 8, 1995, Frank Palluconi, ASTER TIR Vicarious Calibration

This presentation described a field experiment using a set of 12 temperature recording buoys in a 300 m by 300 m grid in Lake Tahoe with concurrent radiance measurements. The experiment showed good correlations between the in situ temperature measurements and Thermal Infrared (TIR) radiances.

2.6.1. Feedback

The spatial scale of the experiment is appropriate for the 90 m pixels of ASTER, but not designed for the 1000 m pixels of MODIS.

2.7. Tuesday, August 8, 1995, Zhengming Wan, Vicarious Calibration for MODIS TIR Bands

The proposed vicarious calibration would use the Spectral Infrared Reflectance and Emissivity (SIBRE) System which includes a Fourier Transform Infrared (FTIR) emission spectrometer and pointing structure with a TIR source and reference plate.

Test sites for this vicarious calibration technique would have to include both favorable surface conditions and atmospheric conditions. The surface would need to be at least 3 by 3 km, flat, and homogeneous, with stable surface emissivity and temperature. The emissivity requirements are $\varepsilon > 0.97$, $\delta\varepsilon < 0.002$. The temperature requirements are T > 10 C and $\delta T_S < 0.2$ C.

The atmospheric conditions require a high surface elevation with column water vapor < 0.5 cm, high surface visibility, freedom from clouds, low surface wind speed, and good quality measurements of atmospheric temperature and water vapor profiles. Possible test sights include lakes and grasslands in Tibet and New Mexico.

2.7.1. Feedback

First rate laboratory instrumentation and equipment were presented but member of the workshop considered the requirements for suitable vicarious test sites to be very challenging. While the methodology appears sound it is difficult to evaluate the proposed technique until field data and experience with the method are accumulated.

2.8. Tuesday, August 8, 1995, Kurt Thome, VIS/NIR/SWIR Vicarious Calibration

The Remote Sensing Group of the Optical Sciences Center at the University of Arizona has extensive experience using several techniques for vicarious calibration of satellites. A key component of the techniques is that all of the vicarious methods can be traced to the sun as the primary source.

The workshop presentation started with a description of the specific techniques that are named “Reflectance-based”, “Radiance-based”, and “Solar-radiation-based”. This included the instrumentation, software, and calibration targets, or field sites, that have been used.

The descriptions were followed by detailed error budgets for the techniques. The Reflectance-based approach has a typical VNIR radiance uncertainty with respect to the sun of 5.2%. It is expected that improved instrumentation and analysis, particularly of the diffuse and global downwelling irradiance, could improve the uncertainty to 3.0% with respect to the sun.

The typical uncertainty of the radiance-based approach using aircraft is 3.2% in the VNIR bands. The techniques and uncertainties for SWIR bands should be similar but the uncertainty analysis is not as mature. Improved versions of the radiance-based approach should reduce the uncertainty to 2.1%.

The solar-radiation-based approach is estimated to be 1.5-3.1% for VNIR bands and 3.2-4.2% for SWIR bands. The experience with the SeaWiFS project was that the solar-radiation-based and integrating sphere based calibrations gave consistent results.

The final section of the presentation dealt with the uncertainty analysis for satellite-based cross-comparisons. Preliminary results from several satellites look encouraging.

2.8.1. Feedback

The depth of experience and the detailed and mature understanding of the uncertainties were considered major advantages of these techniques, particularly in the VNIR. Logistical difficulties and the relatively large atmospheric corrections were considered disadvantages.

2.9. Tuesday, August 8, 1995, Hugh Keiffer, Size-of-source Effect

The ability to calibrate and perform radiometric measurements for a single pixel is limited by the Point Spread Function, PSF, (or its Fourier transform the Modulation Transfer Function, MTF) of the instrument.

MODIS is radiometrically calibrated against a uniform radiance source from an integrating sphere of finite spatial extent. Earth scenes will include radiometric structure on spatial scales both larger and smaller then the calibration reference. Consequently radiometric contrasts appear and the PSF is either unknown or not applied as a correction in the scenes; as a result radiometric uncertainties are to be expected.

The presentation engendered lively discussion about the magnitude of the effects. The PSF is difficult to measure at large angles and that lead to discussions of possible natural and artificial targets for PSF determination or cross calibration opportunities.

2.9.1. Feedback

There was general agreement that further analysis of the effect was warranted.

2.10. Wednesday, August 9, 1995, Hugh Keiffer, Lunar Calibration

Using the Moon as a vicarious calibration source has several potential advantages. The moon is extremely stable, its radiance is within the dynamic range of VNIR and SWIR bands, and it is embedded in a black background. Though the moon is stable its libration, spatial variations, BRDF, and spectral variations require the detailed illumination and observation geometry to be considered.

Calibration of spaceborne imaging instruments using the Moon as a vicarious target requires two components. The first component is a program of Earth-based observations of the Moon. The second is spacecraft observations of the Moon and the analysis used to merge the results.

The Earth based observations of the Moon have begun with a dedicated observatory using filters for multiband imaging at 5” resolution in spectral bands from 0.4µm to 2.5µm. Separate telescopes are used in the VNIR (0.35µm to 1.0µm) and SWIR (1.0µm to 2.5µm) regions. The result is a photometric model for each lunar pixel that is comprised of best fit coefficients to a physical photometric model based on Hapke parameters. Completing the model will require lunar observations each month for >4.5 years to map out enough of the lunar libration period.

Atmospheric corrections and ties to the stellar magnitude scale are accomplished by interspersing measurements of standard stars with lunar observations.

Radiometric calibration tied to terrestrial standards is obtained by observing in-dome radiance standards and planned participation in EOS round-robin calibrations.

With the lunar photometric model, knowledge of the spacecraft position, and lunar ephemeris information, a lunar flux image can be constructed for any given time. The high spatial resolution pixels of this image can be summed onto instrument image pixels to produce an at aperture radiance product to compare to instrument counts.

The sharp edge of the bright moon against the black background may also provide information about scattering characteristics of MODIS.

The expected radiometric uncertainty for VNIR bands is 1.1% with a maximum estimate of uncertainty of 2.5%.

2.10.1. Feedback

Members of the workshop believe the extreme stability of the Moon allows for the possibility of high accuracy. The Moon is also valuable as an independent vicarious source and as a cross calibration target. The uncertainty estimates are difficult to judge until the system is functioning and more experience is gained with this technique.

2.11. Wednesday, August 9, 1995, Menghua Wang, Atmospheric Correction Algorithms for the Ocean Color Sensors

Ocean color measurements require accurate atmospheric correction algorithms to extract the water leaving radiance signal from the top of atmosphere signal that may be 20 times larger. The total signal includes molecular scattering terms, aerosol scattering terms, multiple scattering terms, and radiance from sun glint. Regions of sun glint, like cloudy regions, are masked out of the data and not considered.

Earlier algorithms used for CZCS assumed a single scatter model for aerosols and an “exact” knowledge of the molecular scattering behavior. Band ratios in selected pixels fixed parameters of aerosol models that were applied to an entire scene.

For SeaWiFS and MODIS the multiple scattering has to be explicitly accounted for. Additional bands allow more aerosol parameters to be determined for each pixel and more accurate corrections to be applied on a per pixel basis.

Simulations with aerosol models indicate that the challenging atmospheric corrections problems can be handled for MODIS and SeaWiFS. This presentation was not designed to present a specific vicarious calibration measurement.

2.12. Wednesday, August 9, 1995, Dan LaPorte, TIR Vicarious Calibrations

The Atmospheric Emitted Radiance Interferometer (AERI) and the High resolution Interferometer Sounder (HIS) are Fourier transform interferometers that measure TIR spectra with high spectral resolution and good radiometric calibration.

The AERI has been used as a ship-board instrument to measure thermodynamic sea surface temperature by determining sea surface emissivity, sea surface brightness temperature, reflected sky light, and atmospheric absorption. Based on comparisons to direct thermometry the error in the AERI derived sea surface skin temperature is likely to be less than 0.1 C.

The HIS instrument is an aircraft-borne instrument that can fly up to 20 km above the surface in an ER-2. Direct comparisons between AERI and HIS measurements yield sea surface temperature (SST) agreement to 0.04K. Comparisons of HIS and GOES satellite derived SST measurements agree within 0.5 K for the same spectral bands. While the differences are considered significant it was not clear if GOES or HIS is more accurate.

The AERI has a very thorough traceability and error assessment for the blackbody calibration. Total absolute errors at 2200 cm^{-1} for an instrument temperature of 260 K and source brightness temperatures from 100 K to 320 K are less than 0.35 K. Comparable total absolute errors at 700 cm^{-1} are less than 0.27 K.

2.12.1. Feedback

Using HIS and AERI were considered very powerful techniques with good traceability to standards and demonstrated low uncertainties. The presented analysis was not for a TOA radiance product per se, but a surface SST product. Similar measurements for vicarious calibration would have to include uncertainties for colocating MODIS pixels. HIS is comparable to the HAUCSS technique because it has small atmospheric corrections to TOA radiances. If HIS could look upward as well as downward then nearly complete characterization of relevant atmospheric parameters might be achieved.

2.13. Wednesday, August 9, 1995, Dan Knowles, Ed Knight, Thermal OBCs

MODIS uses an on-board blackbody and views of space to calibrate the thermal channels during flight. The OBC blackbody has an anodized V-grove structure and 12 embedded thermistors. The emissivity will be greater than 0.992 and known to 0.004. The temperature scale is traceable to NIST standards and allows the BB temperature to be known to 0.1 K.

The presentation covered the structure of the OBCs used for thermal calibration, the laboratory calibration procedure using a high quality external blackbody, the equations used to convert from counts to radiance in the thermal emissive bands, the assumptions that go into the equations, how those assumptions are verified, and an uncertainty analysis for the radiance product.

The assumptions used in the analysis include the effect of instrument and patch temperatures, the stability of nonlinear coefficients, the scan angle dependence of measured radiance, detector drift, scatter, ghosting, crosstalk, polarization, and that calibration procedures using the SRCA and SD do not influence the thermal calibration.

The uncertainty estimates showed that bands 20, 22, 23, 24, 25, 27, 28, and 30 may not meet MODIS specifications for radiometric uncertainty.

2.14. Wednesday, August 9, 1995, Ed Knight, Flight Operations for Field Campaigns

Ed Knight, who will be responsible for MODIS Flight Operations, would appreciate any information about what state the instrument or spacecraft is required to be in for each field campaign on the EOS-AM1 calendar. The current plans are that during field campaigns there are four constraints on the instrument state. They are that:

1. The spacecraft will be in its nominal orbital orientation.

2. The instrument will be in science day mode.

3. The instrument will be in the nominal operating state, including but not limited to :
   Electronic Calibration will not be on.
   The blackbody will not be heated.
   DC restore will be on.
   Electronic gains and offsets will not have been recently changed.
   The sector definitions will be normal.
   The instrument will be at its nominal temperature.

4. The SRCA will be off unless the field campaign leader specifically requests that it be turned on during the overpass.

2.15. Thursday, August 10 1995, Phil Slater, Joint Preflight Vicarious Calibration Campaigns

Vicarious calibration is valuable as a calibration source. There are many investigators using different methods, equipment, sites, hardware, and software to make vicarious calibration determinations. Therefore something has to be done to evaluate which sources are the most accurate, reliable, and available in a timely manner for incorporation into the Level 1B (L1B) product.

A series of cross calibrations could help in this evaluation. Cross calibration in the field could compare average spectral reflectances, radiances, or temperatures. Field campaigns could also compare derived atmospheric parameters.

Laboratory cross calibrations could check filter bandpasses, fields of view, and linearity. Before and after field campaigns the instruments and artifacts used for calibration could be cross calibrated. This would include calibrations of radiometers for radiance measurements, radiometers for atmospheric transmittance measurements, and reflectance of panels.

Software intercomparisons could use a common set of starting measurements and derive a set of Top of Atmosphere (TOA) radiances. Geometric registration techniques could also be compared.

After the first round of comparisons a reconciliation process should take place to understand the differences and presumably produce better agreement in subsequent joint field campaigns.

Several sites for joint field campaigns were discussed and some preliminary organizational questions were also discussed.

2.16. Thursday, August 10 1995, Bruce Guenther, Incorporating Vicarious Results in Level-1B Product

There was general agreement that the vicarious techniques were best at providing an in band radiance responsivity. Other correction terms in the calibrations like scan angle variations, temperature sensitivity, levels of background subtraction, mirror side variations, and variations between detectors within a band are generally measured with smaller uncertainties by the OBCs.

There was discussion about the importance of a demonstrated record of consistency for data sets and methods used for calibration. A single measurement at a single time is not sufficient for MODIS calibration. There must be multiple consistent measurements over months or years to establish confidence in a data set.

The importance of band ratios for science products was discussed, but a mechanism to maintain those ratios when different techniques are used to calibrate different bands was not established. There was not a general agreement on how vicarious responsivity measurements would be specifically incorporated into the L1B product. MCST agreed to make more specific proposals.

2.17. Thursday, August 10 1995, Bruce Guenther and John Barker, wrap-up and Action Items

Several goals were achieved during the workshop. MCST was better informed about the various vicarious techniques available and more specifically about the uncertainty budgets associated with them. Several members of the vicarious calibration community took a first step towards joint field campaigns that are considered valuable. More general agreement was reached on the specific areas where vicarious calibration is most valuable and where the OBCs and prelaunch characterization have lower uncertainties. A list of specific actions and recommendations was created to continue the process. The action item list is included in section 4 below.

3. Conclusions

1) MCST believes that vicarious calibration is a valuable part of the calibration strategy for MODIS.

2) This workshop was a useful step in the process of obtaining, evaluating, and including vicarious data into the L1B data product.

3) The worksheets provided a useful focus for questions and discussion. The worksheets were successful not by themselves, but with the reviews and discussions. The combination allowed the workshop to reach consensus on most issues of substance. Worksheet three, the mock proposal, was not as successful.

4) The workshop organizers would suggest written abstracts for similar future workshops.

5) Participation by all the science communities within MODIS could increase the value of vicarious calibration efforts.

6) Techniques in the visible and near IR range have current radiometric uncertainties of about 3.2%. SWIR band uncertainties are less mature. The thermal algorithms were presented in the form of Sea Surface Temperatures rather than Top Of Atmosphere radiances. The agreement with GOES was 0.5K. Other techniques (like lunar observations) look very promising but the community needs experience with the techniques to be confident in their use.

7) The uncertainty analyzes presented by Kurt Thome of the University of Arizona group and Dan LaPorte of the University of Wisconsin group were excellent.

8) A single vicarious measurement at a single time is not sufficient for MODIS calibration. There must be multiple consistent measurements over months or years to establish confidence and objective measures of repeatability in a data set.

9) EOS and MODIS require calibration measurements that are traceable to national standards.

10) Joint field campaigns can help establish the constancy and repeatability of some of the many vicarious calibration methods available. Joint field campaigns will not be practical for techniques that use very different target sites like oceans, deserts, and the Moon. Round robin radiometric calibrations can increase consistency for these programs.

11) Further efforts in vicarious calibration for MODIS should be in cooperation with the EOS calibration and validation scientists.

12) There should be a single set of calibration coefficients for MODIS with interband consistency sufficient to preserve the band ratios needed in level 2 products.

13) Vicarious calibration can be used to determine some of the parameters in the equations relating instrument counts to radiances but there are many parameters like mirror side variations, scan angle variations, temperature sensitivities, instantaneous offset values, intraband variations, and others where vicarious calibration is not a useful tool.

4. Action Items

1) Investigate high-altitude sites, such as Lake Titicaca in Peru/Bolivia, for use in Thermal IR Vicarious Calibration campaigns along with the proposed sites in Tibet and New Mexico.
   Assigned: Zhengming Wan
   Due: by Nov. 1995 MODIS Science Team Meeting

2) Request the acquisition of Lewis spacecraft and ASTER imagery at the points of near-simultaneous observations of ground scenes (once every 2 days) for the purposes of cross-calibration between the Lewis and EOS-AM1 spacecraft.
   Assigned: Butler
   Due: by Nov. 1995 MODIS Science Team Meeting

3) Demonstrate that a Point-Spread Function (PSF) can be derived from the pre-launch characterization of the MODIS instrument with sufficient accuracy to use the moon as a radiometric calibration source and to quantify errors associated with “size of source” effects as discussed in Hugh Kieffer’s workshop presentations.
   Assigned: MCST
   Due: by 20 Sep. 1995 SBRC Calibration Review

4) Quantify the expected size-of-source effects on MODIS and effects on accuracy in the MODIS test program Find out from SBRC: with far-field scatter, what is contamination of the space view in all bands/all channels due to warm surround.

Assigned: MCST/Bruce Guenther
Due: by Sep. 20 1995 SBRC Calibration Review

5) **a)** Provide a list of bands used in lunar calibration to Bruce Guenther/MCST
b) Provide data on solar variability in the lunar calibration bands.
Assigned: a) Hugh Kieffer;
b)Bruce Guenther
Due: by Nov. 1995 MODIS Science Team Meeting

6) Obtain (from SBRC) a definitive measurement of the emissivity of the flat plate on the Ground Based Blackbody for MODIS.
Assigned: MCST/Bruce Guenther
Due: by Sep. 20 1995 SBRC Calibration Review

7) Insure that the emissivity of the flight Blackbody is measured in its anodized and sealed configuration.
Assigned: MCST/Bruce Guenther
Due: by Sep. 20 1995 SBRC Calibration Review

8) Determine if the scan mirror reflectivity deficit is emissive, diffuse, or specular. Perform BRDF measurements at 10.3 microns and in other bands; if there is a peak, determine where that energy is going.
Assigned: MCST
Due: ??

9) Investigate the possibility of coordinating HIS and AES instrument flights.
Assigned: Dan LaPorte
Due: 20 Sep. 1995

10) Describe the lunar-based calibration methodology, including the underlying sensitivity of the product to uncertainty in the knowledge and variability of solar spectral irradiance.
Assigned: Hugh Kieffer
Due: ??

11) Coordinate on gray plate calibration of Kieffer's lunar data instrument in daytime.
Assigned: Phil Slater and Hugh Kieffer
Due: Spring 1996 MODIS Science Team Meeting

12) Provide a schedule of when to do lunar view maneuvers in order to get similar libration and phase angles.
Assigned: Hugh Kieffer
Due: Spring 1996 SWAMP meeting

13) Provide list of field campaigns, including Wallops Island, scheduled for next year. (1996)
Assigned: Dan LaPorte
Due: 20 Sep. 1995

14) Insure that a methodology for updating coefficients based on OBC and VC data is in ATBD 95.
Assigned: MCST (Mike Jones/John Barker)
Due: 31 August 1995

15) Contact ARM to determine the surface characteristics of future and proposed sites, with a focus on the desirability of surface uniformity.
Assigned: Dan LaPorte
Due: 20 Sep. 1995

16) Begin work on coordinating cross-calibration field campaigns.

Assigned: Phil Slater
Due: Spring 1996 MODIS Science Team Meeting

Workshop Findings

1) Peter Abel should request that his instruments fly with MAS to provide vicarious calibration for MAS.

2) Request (through Butler) that the capability to calibrate diffuser plates to NIST be extended to 2.5 microns.

5. Attendees

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